PUBLISHED QUARTERLY BY MISSOURI'S LTAP — *LOCATED AT THE UNIVERSITY OF MISSOURI-ROLLA* Vol. 1, No. 4

MLTRC
MISSOURI LOCAL TRANSPORTATION RESOURCE CENTER

UMR

MOinfo

SUMMER ◆ 2003

in this issue

JUNE 22–25
8th International Conference on Low-Volume Roads
Reno, Nevada
www.t2.unr.edu

JULY 28–30
2nd Urban Street Symposium
Anaheim, California
gulliver.trb.org/conferences/USS2

OCTOBER 14–15
MINK Conference
St. Joseph, Missouri
web.umr.edu/~mltrc

Your LINK to Low-Cost Transportation Training

Training is one of the primary tasks of MLTRC. The center provides learning opportunities on a variety of topics at minimal cost. The workshops are designed to meet the needs of state and county agencies around Missouri.

The center's three primary workshops cover work zone safety, flagging techniques, and gravel roads maintenance. This fall the center will offer sessions on these topics in each of the 10 Missouri Department of Transportation districts.

In addition to the scheduled training offerings, MLTRC also helps agencies organize customized learning opportunities to fulfill their specific needs. MLTRC staff members will help find qualified instructors and arrange on-site workshops on the particular transportation subject an agency requests.

MLTRC subsidizes the cost of all training offerings—regular scheduled learning events and customized sessions, alike. This means the cost to participating agencies stays low. With a minimum of 20 participants, workshops are held at the cost of only $10 per person.

If you are interested in holding a training session for your agency, please fill out and return the request form included in this issue. Even if you do not need customized training at this time, please take a moment to complete the suggestions section and let us know what learning opportunities would be of interest to your agency. Reader feedback helps MLTRC continue to expand its programs to meet the needs of cities and counties throughout the state.

THE FINE PRINT:
Mo Info is published quarterly by the MLTRC at the University of Missouri-Rolla. *RD&T Quarterly* is published by the Missouri Department of Transportation, Jefferson City, Missouri. The opinions, findings or recommendations expressed in this newsletter are not necessarily those of UMR, MoDOT or the Federal Highway Administration.

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PRINTING:
Scotts Printing
Rolla, Missouri

ARTICLE SUBMISSION DEADLINES:
March issue = January 20
June issue = April 20
September issue = July 20
December issue = October 20

MLTRC reserves the right to edit content for length and clarity. Please include your name, address, phone number and email address on all submissions. Images that accompany documents via email must be sent as a separate attachment and resolution must be at least 300DPI.

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MoDOT BRIDGES the Gap

The hydraulic and structural adequacy of the bridges on street, road, and highway systems is a major concern of many local public agencies of Missouri. Local public entities need to conduct effective bridge evaluations to determine priorities for maintenance, rehabilitation, and replacement. Many of these agencies and their political subdivisions lack the funds to do so.

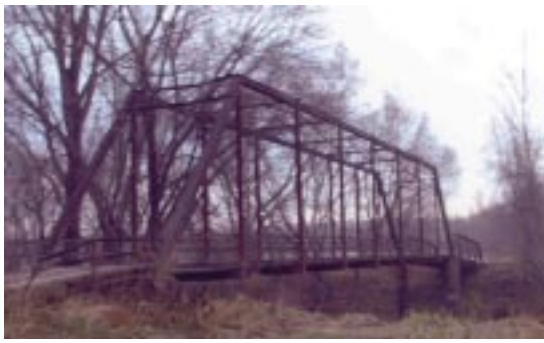
The Missouri Highway and Transportation Commission developed the Bridge Engineering Assistance Program (BEAP) to bridge this gap. The program provides Missouri local public agencies with the assistance necessary to study bridge engineering problems.

BEAP is federally funded. Through the program, private consulting firms with expertise in bridge engineering are retained to aid cities and counties in solving specific operational problems with their existing bridges.

To learn more about accessing BEAP services, contact

2 BRIDGES FOR SALE

LINCOLN COUNTY MISSOURI: Historic bridge available for adaptive reuse and removal. This blend of a Pratt through truss and a Warren Pony truss bridge currently crosses the North Fork of the Cuivre River on Silex Road. Interested parties please contact Steve Dasovich, SCI Engineering, Inc., 130 Point West Boulevard, St. Charles, MO, 63301, 636-949-8200 by May 31.



NODAWAY COUNTY MISSOURI: Bridge No. 526000.8 over the Nodaway River in Nodaway County, Missouri is available for adaptive reuse at a new location. The National Register-eligible bridge is an 11-panel, rigid-connected Parker through truss with steel stringer approach spans. Main span length is 225' and roadway width is 13.4'. Bridge fabricator was the Illinois Steel Company of Chicago, Ill. If the bridge is transferred to another party, the transfer deed may include preservation convenants that require the new owner to preserve and maintain the bridge in accordance with established standards for historic bridges. Funds may be available for reuse of the bridge. Interested parties should contact Clint Mason with Snyder and Associates at 4730 Frederick Avenue, St. Joseph, MO 64506, or by phone at (816) 364-5222.

MLTRC TRAINING REQUESTS & SUGGESTIONS

REQUEST A TRAINING SESSION

Training topic: ❑ Flagger ❑ Work Zone Safety ❑ Gravel Roads Maintenance
❑ Other _____

Date training is needed: _____ Estimated number of participants: _____

Agency: _____

Contact person: _____

Street address: _____

City: _____ State: _____ Zip: _____

Phone: _____ Fax: _____

Email: _____

RANK OUR TRAINING TOPICS

Please rank the following topics in the order of most (1) to least (14) useful to you/your agency:

_____ Pavement Preventive Maintenance (Asphalt)
_____ Funding Options for Elected Officials (e.g., BRO, BRM)
_____ Asset Management/GASB 34
_____ Chip & Seal Maintenance
_____ Snow Plowing
_____ Legal Liabilities Associated with Traffic Control Devices
_____ Bridge Maintenance
_____ Shop & Equipment Safety
_____ Effective Budgeting/Performance Management
_____ Pipe Culvert Installation
_____ Post Earthquake Inspections of Bridges & Box Culverts
_____ Modifying Roadways for Bicyclists & Pedestrians
_____ Proper Use of Emulsions
_____ Wet Lands Issues

RETURN ADDRESS

PLACE STAMP HERE

MLTRC — *Home of Missouri's LTAP*
University of Missouri-Rolla
Civil, Architectural & Environmental Engineering
1870 Miner Circle
Rolla, MO 65409-0030

— Please fold in half and seal with tape (not staples) before mailing. —

SUGGEST A TRAINING TOPIC

Please list other topics which would be useful to you/your agency:

1. _____
2. _____
3. _____
4. _____
5. _____

MINK 3

the conference for county engineers

WHEN:
October 14-15, 2003

WHERE:
Historic Riverfront Hotel
St. Joseph, Missouri

REGISTRATION FEE:
$30

ROOM COST:
$55 + tax

REGISTER ONLINE:
web.umr.edu/~mltrc

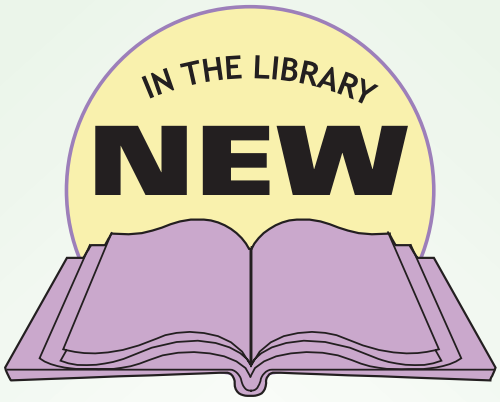
PUBLICATIONS

Retroreflective Sheeting Identification Guide — One-page laminated sheet.

Scenic Byways: A Design Guid for Roadside Improvements — Assists planners, designers and managers of scenic byways. Includes examples of improvements, outlines the planning process, and describes design principles. Covers: scenic byways rpgrams, design considerations, visitor facilities roadway improvements and appendices. 106 pgs.

Traffic Safety Facts 2001 — Public information fact sheets on motor vehicle safety. Pamphlet.

Basic Traffic Control for Utility Operations: Guide for Temporary Traffic control for Utility Operations — Provides a quick reference to utility companies working with temporary traffic control. Basedon the standardsa nd guidelines found in Part 6 of the Manual on Uniform Traffic control Devices (MUTCD) and the requirements of the American with Disabilities Act. Statements made throughout this utility manual concerning issues of accessibility by individuals with disabilities are based ont he draft guidelines developed by the United States Architectural and Transporation Barriers Compliance Board (Access Board), the federal agency charged with developing issued for public review and comment draft guidelines that include accessibility provisions for work zones. Describes only some of the general guildelines, standards and possible applications. It is not possible to address every situation that might arise. Therefore, engineering judgment may be required to fit the conditions of a particular job site. State and local standards may vary. This manual is not inteded to used in lieu of the appropriate standards and specific local requirements. Utility companies should always consult with the appropriate local authorities to determine the specific requriements and any approvals and permits that may be required. FHWA-SA-03-004



ELECTRONIC PUBLICATIONS

Using Metropolitan ITS Deployment Tracking for Regional ITS Planning: Telling hte Deployment Stroy in Tucson, Arizona — electronic publication examines how the metropolitan planning organization in Tucson, Arizona used the methodology contained in the Metropolitan ITS Deployment Tracking Database to develop its ITS Strategic Deployment Plan. FHWA-OP-02-035

Intelligent Transportation Systems in Work Zones: A Crosscutting Study — Examines how departments of transportation in Illinois, Michigan, New Mexico and Arkansas used ITS in their work zones and recounts the benefits they experienced. Also profeils other ITS-related work zone products, systems and techniques. FHWA-OP-02-025

Asphalt Pavement Maintenance Field Guild — The PDF version of the previously released Asphalt Pavement Maintenance Field Guild is now available online at: www.umr.edu/~mltrc/library/index.html
This publication was produced by the Minnesota LTAP, Minnesota Department of Transportation Offic of State Aid, Minnesota Local Road Research Board and FHWA.

VIDEOS

Public Works Mutual Aid — Describes the New Hampshire Public Works Mutual Aid Program in which local governments agree to provide equipment and personnel to other members when needed during and after an emergency. 9 minutes.

POSTERS

Work Zone Safety Awareness Week Poster

To check out items in the MLTRC library, please visit our website or call toll free 1-866-MO-ROADS (667-6237).

SEASONAL TIP:
Watch Out For Wildlife!

Many highways on or near National Forest System lands wind their way through excellent wildlife habitat. Florida's highways slice through rare black bear habitat. Alaska struggles with moose-vehicle collisions. Grizzly bears in the northern Rockies are killed on highways or avoid crossing them to reach other parts of their recovery zones. U. S. Department of Agriculture (USDA) Forest Service wildlife biologists and transportation planners wrestle with how to plan wildlife-friendly highways or reduce impacts from those already on the landscape.

San Dimas Technology and Development Center has partnered with Utah State University, the Western Transportation Institute, and the U.S. Department of Transportation Federal Highway Administration to create a toolkit that provides assistance. The Wildlife Crossings Toolkit is an online source of excellent information on wildlife/highway interactions. The toolkit contains two major sections.

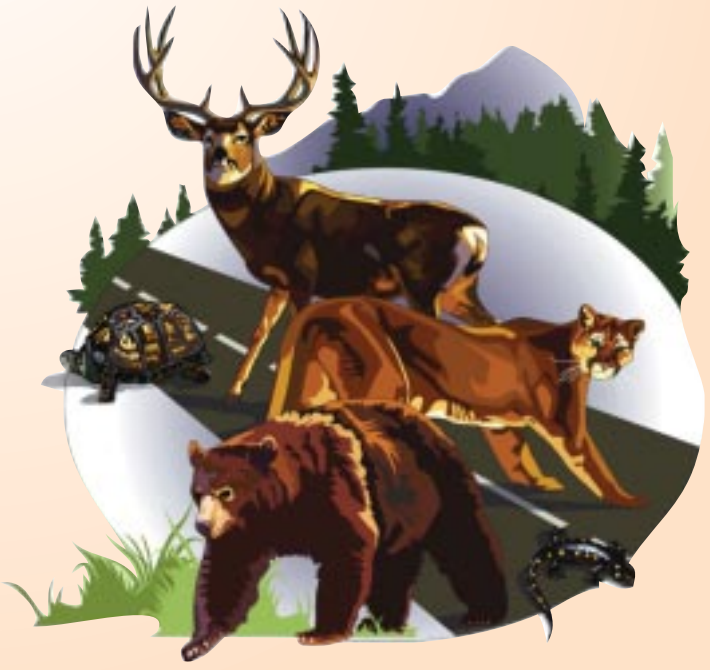
The first is a fully searchable database of case histories from around the world of projects that have considered wildlife in the planning or retrofitting of solutions to highway-caused impacts to wildlife. Most of the case histories show how engineers and biologists have worked together across disciplines to solve some almost intractable problems. Other histories show how projects could have worked better: each account has a section on how the planners would have proceeded differently. Most case histories contain plans, drawings, and images from the projects for engineers to use as a starting point for their own work.

The second major part of the toolkit is comprised of articles and links to resources that will help engineers and biologists quickly find information on highway impacts to wildlife and successful solutions to reduce those impacts. Relevant articles by the world's experts explain concepts in clear, concise terms understandable to both disciplines.

The toolkit is designed to encourage engineers and biologists to work together for innovative solutions. An extensive illustrated glossary and standardized terminology help foster this effort.

The Wildlife Crossings Toolkit is the major source material for a new FY03 training session Innovative Solutions to Wildlife/Highway Interactions for biologists and engineers.

Check out www.wildlifecrossings.info



Source: United States Department of Agriculture Forest Service Department of Transportation, Technology & Development Program

WE WANT TO HEAR FROM YOU!

Let us know if your address has changed.
Visit our website to update your information!

tel (toll free) 866-667-6237 *email* mltrc@umr.edu *website* www.umr.edu/~mltrc

Research, Development and Technology
Quarterly
Missouri Department of Transportation
Vol. 7, No. 2

Laboratory testing of bridge deck mixes

Project Description

Early crack development has been noticed in many of MoDOT's bridge decks. The cracks have been attributed to high thermal or shrinkage stress development at early ages in the concrete. These cracks accelerate concrete deterioration and corrosion of reinforcing steel that shorten the service lives and increases the maintenance costs of bridge decks.

This study was conducted to develop a new bridge deck mix design that has low cracking potential, low permeability, good durability, and adequate strength. The mix designs developed in this study will improve field performance and minimize cracking potential compared to MoDOT's current (B-2) bridge deck mix design.

Laboratory-testing on 11 different PCC bridge deck mix designs were conducted. Each test mix differed by the type and/or the amount of supplementary cementitious material that replaced Type 1 Portland cement. The different mix designs are described in Table 1. The supplementary cementitious materials used in this study included Class C flyash, ground granulated blast furnace slag (GGBFS), silica fume, and ternary combinations of these materials.

The following tests were conducted to evaluate and compare the concrete characteristics for each mix design:

FRESH CONCRETE CHARACTERISTICS

- Slump (AASHTO T119)
- Percent Air Content (AASHTO T152)
- Unit Weight (AASHTO T121)
- Water/Cement Ratio
- Finishing Observations

MISSING TEXT? ---->

MIX #	CEMENTITIOUS MATERIALS
1	Control, 728 lb/yd3, No Water Reducer
2	Control, 728 lb/yd3- 15% Flyash, No Water Reducer
3	602 lb/yd3, Type A Water Reducer
4	602 lb/yd3- 15% Flyash, Type A Water Reducer
5	602 lb/yd3- (35% Flyash), Type A Water Reducer
6	602 lb/yd3- (25% Slag), Type A Water Reducer
7	602 lb/yd3- (50% Slag), Type A Water Reducer
8	602 lb/yd3- (6% Silica Fume), Type A Water Reducer
9	602 lb/yd3- (15% Flyash & 25% Slag), Type A Water Reducer
10	602 lb/yd3- (15% Flyash & 6% Silica Fume) Type A Water Reducer
11	602 lb/yd3- (25% Slag & 6% Silica Fume), Type A Water Reducer

Table 1 – Mix Descriptions

CRACKING POTENTIAL

- Plastic Shrinkage Test in Slabs — Research Test
- Cracking Tendency of Concrete Ring — Research Test
- Autoclave Expansion (ASTM C151)
- Dry Shrinkage of Mortar Bars (ASTM C596)

PERMEABILITY

- Rapid Chloride Permeability (AASHTO T277)
- 90-Day Ponding Test (AASHTO T259)

DURABILITY

- Freeze/Thaw Durability (AASHTO T161)
- Salt Scaling Resistance (ASTM C672)

STRENGTH PROPERTIES

- 3, 7, 14, 28, 56, and 90 day compressive strength (AASHTO T22)
- Heat of hydration (ASTM C1074)
- 3, 7, 14, 28, and 56 day modulus of elasticity (ASTM C469)

Laboratory Results

FRESH CONCRETE CHARACTERISTICS

Emphasis was placed to make each mix design equal in workability using the slump test and the percent air content as guides. The target slump was 3 _ inches and the target air content was 6%. The water/cement ratio was measured at these target values.

CRACKING POTENTIAL

Laboratory tests that determine the cracking potential of a concrete mix designs were conducted, however all test results from the plastic shrinkage test of slabs, cracking tendency of concrete rings, autoclave expansion, and dry shrinkage of mortar bars, were inconclusive in evaluating and comparing the cracking tendencies of the different mix designs.

PERMEABILITY

Two permeability tests were conducted to determine the concrete's resistance to chloride ion penetration. The 90-day ponding results showed favorable results for all mix designs tested, but failed to compare the different mix designs. The rapid chloride permeability (RCP) test effectively evaluated the eleven mix designs.

Mixes that did not contain supplementary cementitious materials (Mix 1 and Mix 3) yielded over 2000 Coulombs, which is considered moderate permeability. Class C flyash or GGBFS replacement in a concrete mix (Mix 4 and Mix 6) yielded low permeability at 90 days. Increasing the replacement dosage of flyash and GGBFS (Mix 5 and Mix 7) further decreased the permeability into the low and very low ranges for the 28, 56, and 90-day tests. Mix 9 contained a ternary combination of 15% Class C flyash and 25% GGBFS that yielded low permeability.

BEYOND THE PAVEMENT:

The Social/Economic and Environmental TAG covers new ground

TAGs PART II

The Missouri Department of Transportation (MoDOT) relies on six Technical Advisory Groups (TAGs) to provide direction and input regarding innovative practices, methods and products that should be evaluated for use in Missouri. This issue will highlight activities of the Social, Economic, and Environmental (SEE) TAG.

The SEE TAG is responsible for reviewing and initiating MoDOT research and development activities that address the social/community, economic, and environmental implications of our transportation system. The group addresses such broad issues as community development and its link to transportation; economic development in relation to transportation; transportation affects on communities; neighborhoods and population groups; organizational policy; environmental compliance and betterment; and general policy studies. The SEE TAG generally meets quarterly throughout the year to review research ideas submitted by citizens, agencies, and companies around the state.

The following are examples of research projects currently under the direction of the SEE TAG:

ENVIRONMENTAL ROADSIDE INVENTORY — With the help of District 3 staff in Hannibal, MoDOT is using GPS and GIS technology to develop an environmental and roadside inventory of the Highway 36 corridor. Project results will be used to reduce mowing and herbicide application through better management of the prairie remnant that exists in the area. The project also represents a major step in adopting asset management strategies for the 385,000+ acres of right of way owned by MoDOT.

FACILITATION OF SAFETY EVALUATIONS OF NIGHTTIME AND DAYTIME WORK ZONES, NCHRP PROJECT 17-30 — The National Cooperative Highway Research Program has selected this project proposal from the SEE TAG group for a national-level study. The

research focuses on three objectives: 1) analysis of available work zone accident data to make conclusive statements regarding the relative danger of traffic crashes in nighttime versus daytime work zones; 2) evaluation of the nature of crashes in nighttime and daytime accidents, and 3) identification of the best management practices to ensure safety in nighttime work zones.

DEVELOPMENT AND USE OF SOCIAL AND ECONOMIC DATA AT MODOT — In conjunction with the Office of Social and Economic Data analysis at the University of Missouri, MoDOT recently posted the Social, Economic Indicator Resource (SEIR) website. The site provides accurate, timely and reliable census and economic data, customized for specific geographies used in transportation planning and project development. The data is not only relevant to MoDOT activities, but has proved useful for transportation stakeholders and partners as well. View and use the SEIR website at http://oseda.missouri.edu/modot/

IDENTIFICATION OF THE BENEFITS AND CRITERIA FOR PASSING LANES IN MISSOURI — This joint project with the Midwest Research Institute will identify criteria for and conditions of two-lane state roadways across the state where passing lanes may improve the level of service and safety.

ECONOMIC DEVELOPMENT IMPACTS OF FOUR-LANE HIGHWAYS FOR NON-METRO MISSOURI — Undertaken in conjunction with the Department of Rural Sociology and the Community Policy Analysis Center at the University of Missouri, this project seeks to identify economic and community development benefits associated with four-lane highway facilities. The research addresses the question of whether four-lane highways can aid in the generation of economic and community development in rural areas.

THE SOCIAL/ECONOMIC AND ENVIRONMENTAL TAG CONSISTS OF THE FOLLOWING MEMBERS:

TOM JOHNSON, PhD
University of Missouri-Columbia

KATE TRAUTH, PhD
University of Missouri-Columbia

GARY SPRING, PhD
University of Missouri-Rolla

PEGGY CASEY
FHWA

MARK KROSS
MoDOT — Project Development: Environmental

JOHN MARTIN
MoDOT — Right of Way

PAULA GOUGH
MoDOT — Planning

KATHY WHITE
MoDOT — Planning

JAY WUNDERLICH
MoDOT — Governmental Affairs

AUGIE TIMPE
MoDOT — Maintenance

MELISSA ANDERSON
MoDOT — Research, Development and Technology

MIKE SHEA
MoDOT — Research, Development and Technology

ERNIE PERRY
MoDOT — Research, Development and Technology

DO YOU HAVE AN IDEA?

If you have a research idea that could benefit the state transportation system or a new product to be reviewed, please fill out the corresponding RIS or New Product Evaluation form included in this issue.

MoDOT wants to hear from you!

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

RESEARCH IDEA STATEMENT

Check the appropriate area(s): ❒ Geotechnical ❒ Operations ❒ Pavements ❒ Traffic/Safety
❒ Social/Environmental/Economic ❒ Project Development/Bridge

IDEA TITLE: _____

IDEA STATEMENT: _____

_____

OBJECTIVE: _____

_____

_____

_____

APPLICATION(S)/BENEFIT(S): _____

_____

_____

_____

_____

KEY WORD *(Key words are needed to assist in literature search for research idea subject):*

_____

_____

DATE: _____

NAME: _____ **TITLE:** _____

ORGANIZATION: _____ **DIV/DIST:** _____

ADDRESS: _____ **CITY/ZIP:** _____

PHONE: _____

Complete and return to:
Missouri Department of Transportation
Attn.: Research, Development & Technology
PO Box 270
Jefferson City, MO 65102
FAX: (573) 522-8416

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

PRODUCT LISTING/NEW PRODUCT EVALUATION REQUEST FORM

CONTACT INFO

When request is submitted, enclose a completed copy of this form and the required information as indicated below.

❒ Manufacturer ❒ Fabricator ❒ Distributor ❒ Other _____

Business Name _____ Contact Name _____

Address _____ City _____ State _____ Zip _____

Telephone Number _____ Fax _____

Email _____ Website _____

PRODUCT INFO

Manufacturer _____

Name of Product _____ Model No. _____

Description and intended application of product: _____

Key Words *(requested for literature search):* _____

List other states using the product: _____

What is the approximate unit cost of the product? _____

Is material available at no cost for lab and field installation evaluation? _____

SPECS

Does the product comply with MoDOT specifications? ❒ Yes ❒ No

If yes, provide specifications name/number.

If no, attach separate explanation as to why not and why MoDOT should consider the product.

Does product comply with other specifications (such as ASTM, ITE, AASHTO, NEMA, NTPEP, etc.)? ❒ Yes ❒ No

REQUIRED INFO

In addition to this form, please submit the following:

1) Product data (mixing info, installation requirements, product brochures, specification sheets, etc.)
2) Decoumentation required by the MoDOT specification (if applicable)
3) Applicable test data
4) Unit cost data and whether the unit cost includes installation
5) Material Safety Data Sheet

SIGNATURE

SUBMITTED BY:

_____

Signature *Print Name* *Date*

MAIL TO

Please send the new product evaluation request form and all other required information to the appropriate address below. Submittals related to the Traffic Signal and Highway Lighting Approved Products List should be submitted to Traffic Operations. Submittals that meet a current MoDOT specification and have a Qualified or Pre-Acceptance List should be submitted to Project Operations. All other submittals should be submitted to Research, Development and Technology. If a sample is required by the specification, submit the sample with a copy of the required documentation to the Central Laboratory. If the specification does not specify a sample or there is no specification, sample submittals will be required upon request.

Traffic Operations
PO Box 270
2211 St. Mary's Blvd.
Jefferson City, MO 65102

Project Operations
PO Box 270
2211 St. Mary's Blvd.
Jefferson City, MO 65102

Central Laboratory
PO Box 270
1617 Missouri Blvd.
Jefferson City, MO 65102

Research, Development & Technology
1617 Misouri Boulevard
Jefferson City, MO 65102

OFFICE USE

FOR OFFICE USE ONLY:

Initial date received _____ All required documentation submitted? ❒ Yes ❒ No

Date of additional documentation receipt _____ Product Development / NP number assigned _____

Mix 8, which contained 6% silica fume, yielded very low permeability. Adding flyash or GGBFS with the silica fume, Mixes 10 and 11 (both ternary mixes), also yielded very low permeability of less than 1000 Coulombs. The main benefit of silica fume is that it provides a dense, low permeable mix.

DURABILITY

Resistance to freezing/thawing conditions and salt scale resistance were the tests conducted to evaluate the durability of the 11 mix designs. A good quality aggregate was used in this study so that the freeze/thaw resistance of the different types and amounts of cementitious materials could be determined. Freeze/thaw results indicated that all mixes obtained a durability factor greater than 90, which is considered excellent durability.

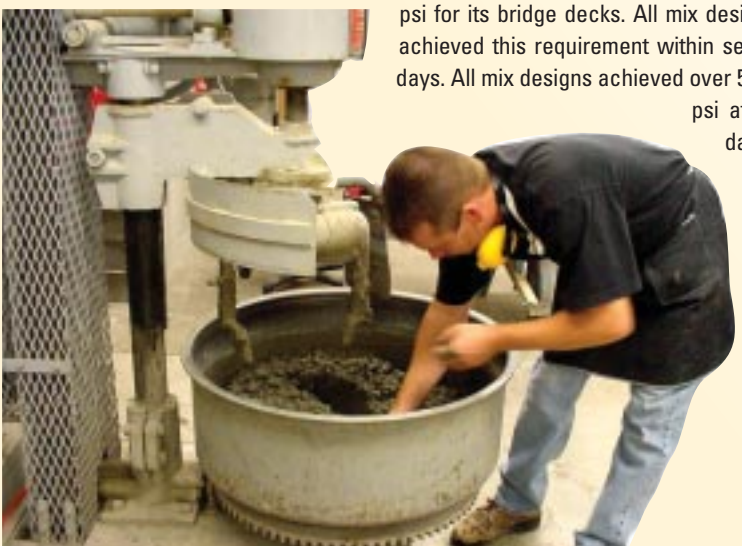
The resistance to salt scaling was observed and rated for each mix design. Salt scale resistance is determined based upon a visual scale ranging from 0 (No Scaling) to 5 (Severe Scaling). The addition of any supplementary cementitious materials (Class C flyash, GGBFS, and/or silica fume) appeared to slightly decrease the salt scale resistance of the concrete, but the effect was not considered significant. The salt scale ratings of mixes containing supplementary cementitious materials (Mixes 4-11) typically rated at a 1 rating (slight scaling) or a 2 rating (slight to moderate scaling).

Increased dosage amounts of Class C flyash and GGBFS (Mix 5 and 7, respectively) did not continue to decrease the salt scale resistance. Also, ternary combinations of cementitious materials (Mix 9, 10, and 11) performed equal or better compared to the single supplementary cementitious mixes.

ASTM C672 is considered to be harsh laboratory test in evaluating a concrete mix's salt scale resistance. A laboratory salt scale rating of 2 or less is considered acceptable for bridge deck applications in Missouri. Field ratings will be conducted on future projects to ensure that salt scaling is not an issue with supplementary cementitious materials.

COMPRESSIVE STRENGTH

Compressive strength data were collected from 3, 7, 14, 28, 56, and 90 day concrete test cylinders that represented each laboratory mix design. Figure 2 graphically illustrates the 3, 7, 28, and 56-day compressive strengths of each mix design. MoDOT has a minimum 28-day design compressive strength requirement of 4000 psi for its bridge decks. All mix designs achieved this requirement within seven days. All mix designs achieved over 5000 psi at 28 days, which is considered more than adequate strength for bridge decks. Lower compressive strengths, especially low early strengths, are generally more desirable for bridge decks because of the lower heat of hydration generated and lower early cracking potential.



When supplementary cementitious materials and a Type A water reducer were used in a mix containing a reduced cement content 6.40 sacks/yd3 (Mixes 4 –11), the compressive strengths were equivalent or higher than the B-2 control mixes. GGBFS has a lower heat of hydration than Portland cement and will generally retard the setting time of concrete. The laboratory results likewise indicated that test mixes 6, 7, 9, and 11 that contained ground granulated blast furnace slag (GGBFS) yielded a lower 3 and 7-day compressive strengths compared to all other mixes as illustrated in Figure 2. After 7-days, the compressive strengths of the GGBFS mixes compared similar to the B-2 control mixes.

HEAT OF HYDRATION

Lowering the heat of hydration of a concrete mix is one of many recommendations to reduce thermal stresses and mitigate early bridge deck cracking. Peak hydration temperatures were measured on 4"x 8" specimens for each of the mix designs. Reducing the cement content from 7.74 sk/yd3 to 6.40 sk/yd3 reduced the heat generated. Mixes containing Class C flyash and GGBFS yielded even lower peak temperatures. Silica fume mixes (Mixes 8-11) had higher peak temperatures than the flyash and GGBFS mixes but was lower compared to the B-2 mix (Mix 1) containing 7.74 sk./yd3 of Portland cement.

MODULUS OF ELASTICITY

The modulus of elasticity affects both thermal and shrinkage stresses more than any other physical concrete property. Increasing the concrete modulus of elasticity increases both shrinkage and thermal stresses.

Modulus of elasticity testing was performed on 3, 7, 14, 28, and 56-day cylinders that were fabricated to represent each of the 11 different mix designs. Results indicated that mixes containing GGBFS (Mix 6, 7, and 9) had lower early 3-day modulus of elasticity (Approx. 3.6 million psi.) compared to the other mix designs (4.0 – 5.6 million psi.). The benefits of using GGBFS are that it provides concrete with a low early strength and low early modulus to reduce thermal and shrinkage stresses in concrete, therefore reducing the potential for early cracking in bridge decks.

Mix 8 (6% silica fume replacement) provided a higher early 3-day modulus (5.6 million psi) and therefore more sensitive to early cracking. Using silica fume in combination with flyash or GGBFS decreased the early 3-day modulus of elasticity to 4.0 million psi.

COST ANALYSIS

The cost of the 11 different mix designs were estimated and compared to determine the most cost effective mix design. The eleven mix designs differed mostly by type and amounts of cementitious material and the addition of a Type A water reducer. The prices of cementitious materials may vary considerably and depend on project location, project size, and available shipping means.

According to the cost estimate reducing the minimum total cementitious materials from 7.50 sk./yd3 to 6.40 sk/yd3, replacing Portland cement with Class C flyash and GGBFS, and the addition of a Type A water reducer will provide MoDOT with a savings of approximately $6.00/yd3. The use of silica fume would increase the cost of MoDOT's bridge decks by approximately $8.00/yd3.

continued on next page...

TECH BRIEFS

Key Findings

The main findings of this investigation can be summarized as follows:

- All mixes tested in this study achieved acceptable compressive strength and excellent freeze/thaw durability factors.
- Reducing Portland cement content to 6.40 sk/yd3 achieved more than adequate strength for Missouri's bridge decks.
- Replacing Portland cement with a supplementary cementitious material in the 6.40 sk/yd3 mixes yielded compressive strengths equivalent to or greater than the control mixes.
- Mixes containing 25% and 50% GGBFS yielded lower early strengths and lower early modulus of elasticity compared to other mixes. Concrete with lower early strength and lower early concrete modulus have less thermal and shrinkage stresses that cause early bridge deck cracking.
- Decreasing total cementitious content and the use of supplementary cementitious materials slightly decreased the salt scale resistance of concrete. However, these results and the results from all mixes tested were found acceptable for bridge deck applications in Missouri.
- The use of flyash, GGBFS, and/or silica fume significantly decreased concrete's permeability. Concrete mixes without a pozzolan or cementitious admixture yielded moderate permeability, which is too high to be acceptable for bridge deck applications in Missouri.

Recommendations

Based on the laboratory results from this study, Research, Development, and Technology makes the following recommendations:

- The minimum total cementitious material in bridge deck mixes should be reduced from 7.50 sk/yd3 to 6.40 sk/yd3 to reduce the drying shrinkage potential and thermal stresses that induce cracking in bridge decks.
- The addition of a Type A water reducer should be used in bridge deck mixes to ensure strength, permeability, and workability requirements.
- At least one of the following supplementary cementitious materials should be incorporated into bridge deck mixes at the recommended replacement limits.

SUPPLEMENTARY CEMENTITIOUS MATERIAL	MAX. LIMITS
Max. Flyash Replacement	25%
Max. GGBFS Replacement	40%
Max. Total Portland Cement Replacement w/ Supplementary Cementitious Materials	40%

- A ternary mix containing Type 1 Portland cement, 15% flyash, and 25% GGBFS (Mix 9) should be encouraged and used whenever possible because of its superior concrete properties, lower cost, and its desired compatibility compared to mixes containing Type 1 Portland and Class C flyash.
- Silica fume is not recommended based upon cost, workability issues, and its plastic shrinkage cracking potential.
- Field documentation and verification should be conducted to verify the performance of the bridge deck mix designs proposed in this study.

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